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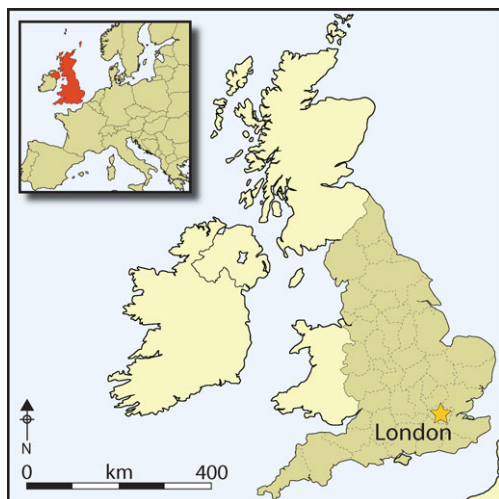
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# What was a mortarium used for? Organic residues and cultural change in Iron Age and Roman Britain

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*The Romans brought the mortarium to Britain in the first century AD, and there has long been speculation on its actual purpose. Using analysis of the residues trapped in the walls of these ‘kitchen blenders’ and comparing them with Iron Age and Roman cooking pots, the authors show that it wasn’t the diet that changed — just the method of preparing certain products: plants were being ground in the mortarium as well as cooked in the pot. As well as plants, the mortars contained animal fats, including dairy products. The question that remains, however, is why these natural products were being mixed together in mortaria. Were they for food, pharmaceuticals or face creams?*

**Keywords:** Iron Age and Roman Britain, first–fourth centuries AD, mortaria, diet, lipids

## Introduction

The Roman ceramic *mortarium* is a robust, open form of bowl or basin, with a prominent rim and spout. The earliest mortaria recovered from Britain, which date to the later Iron Age, are continental imports discovered at sites located predominantly in the south-east (Hartley 1981, 1985). The frequency of these artefacts suggests that the scale of trade was initially low, perhaps incidental to other larger-scale trade. After AD 43, both imported and locally-made mortaria became increasingly common in Britain and two major centres began to dominate the market, one of which was situated south of Verulamium (St Albans) and the other in either Gallia Belgica or south-eastern Britain (Dickinson & Hartley 1971). By the later

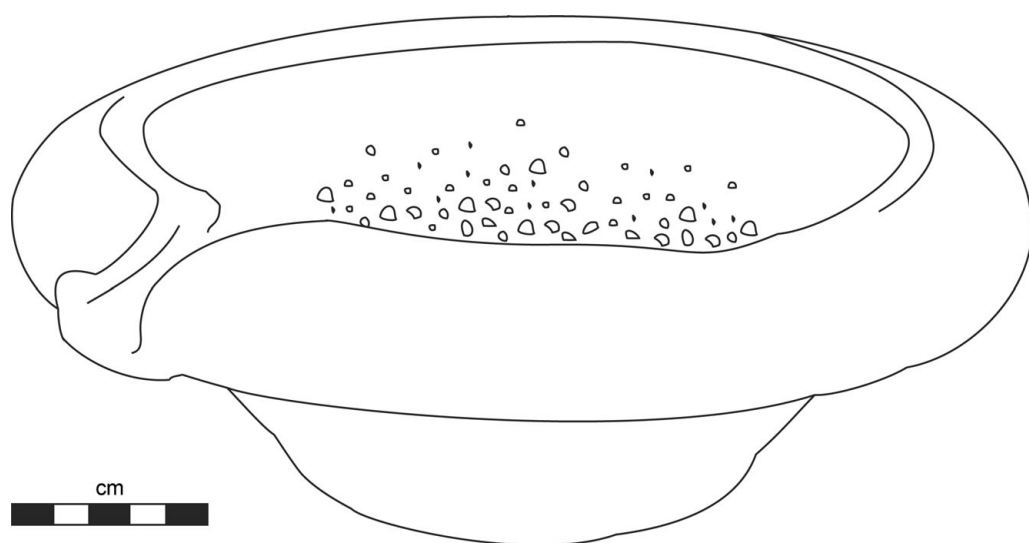
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*Figure 1. Drawing of a typical mortarium found in Roman Britain.*

first century, however, imports had all but ceased, with only very low numbers of Gaulish mortaria present after AD 100 (Hartley 1973). Production was no longer confined to south-east Britain, with many other industries in the Midlands and further north producing and distributing mortaria alongside the still-dominant south-eastern production centres. From the later second century mortaria became more frequent and their distribution spread from a predominantly urban and military distribution to rural settlements. At rural sites in the north and west of the province of Britannia they are often found to comprise a relatively significant proportion of the overall ceramic assemblage (Evans 1995; Tyers 1996; Rush 1997; Cool 2004, 2006) even if the overall contribution of Roman-type pottery remained low.

The earliest mortaria in Britain were straight (wall)-sided, often with incised lines scored around the interior providing a roughened surface (Hartley 1981, 1985; Parminter & Hartley 1996). These examples were usually not spouted. However, by the mid first century this version became obsolete, being replaced by the classic mortarium exhibiting a well-defined rim and flange, with coarse trituration grits replacing the internal scoring (Figure 1). Regional or industry-specific styles developed over time, including the Mancetter-Hartshill 'hammer-head' form and the Oxfordshire colour-coated wares imitating earlier Gaulish Samian ware imports. Although distinctive in form, the size, fabric and style of mortaria could vary widely; whilst most fall within the range of 20–30cm in diameter, miniature vessels and examples reaching 1m in diameter are also known (Phelps 1923). Spouts, when present, could be flat and broad, a mere finger impression on the rim or a pierced hole through the vessel wall. Decoration was uncommon, but painted, stamped, incised or rouletted examples are known (Young 1973, 1977).

Heavy wear has been observed on some sherds (Hartley 1981, 1990; Parminter & Hartley 1996), which, combined with the presence of the trituration grits, indicate that the vessels may have been subjected to considerable abrasive activity. Sooting or burning is

not ubiquitous but has been observed on sherds from a range of sites (Oswald 1943: 45–6; Hartley 1990: 194–5, 1999: 109; May 1996: 565).

According to Roman sources, mortaria were used to mix together a range of ingredients, including herbs and spices, meat, oil, fish sauce and wine, in order to prepare dishes such as rissoles, sauces and *moretum* (a kind of cheese-bread; e.g. Cato the Elder, *De Agricultura* 75–6; Dalby 1998). Apicius and Columella refer to a mortarium in the context of culinary preparations, often with reference to mixing or pounding of ingredients: “Put in a mortar pepper, caraway, coriander, asafoetida root, mint, rue; pound; moisten with vinegar, add Jericho dates, pour over some of the cooking liquor” (Apicius, *de re Coquinaria*; Flower & Rosenbaum 1958).

Other evidence for the use of mortaria can be derived from visual representations in contemporary artefacts, including a Roman figurine of unknown provenance on display in the Ashmolean Museum, Oxford. This depicts a mortarium in use by a seated figure, although the nature of the contents is ambiguous. A similar figurine, of Egyptian origin, is exhibited at the British Museum and depicts a slave mixing or grinding substances in a mortarium whilst wiping an eye — this latter gesture interpreted as indicating the grinding of onions (British Museum; Figure 2). A two-dimensional depiction of mortaria, alongside pestle-shaped objects and a range of other culinary objects and food items, can be identified in a mosaic from Malaga (Blázquez 1981).

Does the introduction of the mortarium signal the adoption of new ‘Roman’ style of food preparation (e.g. Evans 1995), or was it a new utensil put to the service of existing Iron Age cuisine, such as making cheese (Oswald 1943) or cereal processing (Phelps 1923; Hartley 1973; Alcock 2001)? This paper reports a study undertaken to establish the types of commodities that were being processed in mortaria, through the characterisation of residues preserved in the fabric of the vessels. The residues in Roman mortaria from seven sites (six British and one continental) were compared with residues from Roman cooking wares in two British sites and Iron Age cooking wares from four British sites (Table 1).

## Method

Methods for the detection and identification of organic residues absorbed in the walls of unglazed pottery are well established. Preserved lipids may be extracted from the fabric of pottery using organic solvents and these mixtures of lipids separated and characterised using gas chromatography (GC) and GC/mass spectrometry (GC/MS), providing a ‘fingerprint’ that may be related back to the original contents of the vessels. Further specification as to the origin of fats is obtained through the analysis of the stable carbon isotopic composition of the individual fatty acids present in the lipid residues (Heron *et al.* 1991; Evershed *et al.* 1990, 1992, 1999; Dudd *et al.* 1999; Evershed ?).

## Results

The residues examined here were selected from some 600 Roman vessels deriving from 15 assemblages, on the basis of their containing appreciable concentrations of lipids. These are compared with previously published data from 237 Iron Age vessels (Copley *et al.* 2005).



*Figure 2. Figure of a slave handling substances in a mortarium whilst rubbing his eye. Origins: Egypt, c. AD 200 (© The Trustees of the British Museum).*

Despite the high number of vessels investigated, lipid recovery from mortaria was poor, such that only vessels from seven of these assemblages are considered further. Moreover, although the proportion of sherds containing residues from all types of vessel appears consistent, it was noted that absolute lipid concentrations recovered from mortaria were distinctly lower than both Iron Age and Roman ‘cooking’ vessels recovered from the same site (Figure 3). These low concentrations may be due to the predominant use of the mortarium to grind plants without heat: it has been shown that residues are more easily absorbed when heated, and animal tissues release higher concentrations of lipids than most plant tissues (Charters *et al.* 1993; Charters 1997; Evershed 2008).

The plant-derived components that were identified in the mortarium sherds include ranges of long-chain odd-carbon number *n*-alkanes, even-carbon number *n*-alkanols,

Table 1. Summary of sites from which pottery residues are discussed. Sites from which lipid preservation was very poor are not included in this table but these included 180 vessels from Deansgate (Manchester), Heybridge, (Essex), Leicester (Leics.), Rutland Villas (Leics.), Sedgefield (Co. Durham), Silchester (Hamps.), Pompeii (Campania, Italy) and Carthage (Tunisia).

Site	Region	Type	Number of vessels analysed		<i>n</i> (%) vessel residues characterised
			Mortaria	'Cooking' vessels	
Danebury†	Hampshire	Iron Age hillfort		69	33 (48)
Maiden Castle†	Dorset	Iron Age hillfort		54	41 (76)
Yarnton	Oxfordshire	Iron Age settlement		49	28 (57)
Cresswell†					
Faverdale	Co. Durham	Roman rural farmstead	22	55	Mortaria: 10 (46) cooking: 41 (66)
Fishbourne	W. Sussex	High status Roman 'palace'	26	n/a	4 (15)
Piercebridge	Co. Durham	Roman villa/small town and later fort	29	n/a	20 (69)
Stanwick†	Northamptonshire	Iron Age and Roman agricultural village	38	Iron Age: 65 Roman: 93	Iron Age cooking vessels: 39 (60) Roman mortaria: 25 (66) Roman cooking: 31 (52)
Stonea Grange	Cambridgeshire	Roman ?imperial administrative centre	20	n/a	13 (65)
Wroxeter	Shrewsbury	Roman legionary fortress and <i>Civitas</i> capital	71	n/a	33 (46)
Xanten	Westphalia, Germany	<i>Colonia</i>	40	n/a	20 (50)

n/a = not analysed

†Iron Age data published in Copley *et al.* 2005

mid-chain ketones, plant sterols and even intact wax esters (Figure 4). When compared with other Roman domestic 'cooking' vessels, the high frequency of plant waxes in mortaria is clearly distinctive (Figure 5). Although mixtures of fats of animal and plant origin were identified in all of the vessel groups, plant-derived residues were observed with exceptional frequency in Roman mortaria, occurring in 60 to >90% of the diagnostic residues. Animal tissues yield a higher concentration of lipids than plant tissues (Dudd 1999), such that animal product processing is usually quantitatively over-represented.

*n*-nonacosane was usually the major component of plant-derived lipid residues; however, this is a relatively ubiquitous component of plant lipids and further,

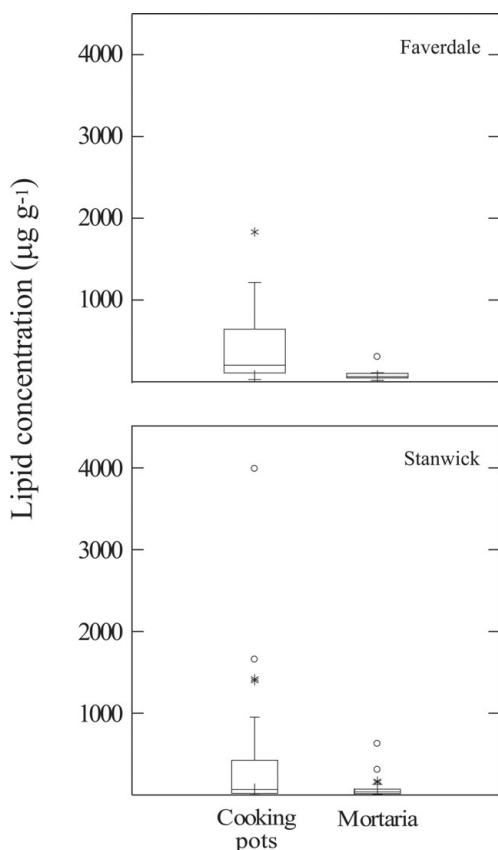


Figure 3. Box plots derived from the lipid concentrations from absorbed residues preserved in Roman pottery from Stanwick and Faverdale.

one that is more likely to resist decay compared with alkanols and ketones (Charters 1997) or shorter-chain homologues (Regert *et al.* 2001). Other components present include *n*-alkanes within the range  $C_{27}$ – $C_{33}$ , *n*-alkanols between  $C_{24}$ – $C_{32}$  and the mid-chain ketone nonacosan-15-one. Intact wax esters were detected in residues from Faverdale, Stanwick and Wroxeter; these were predominantly in the range  $C_{44}$ – $C_{52}$  with fatty acid moieties of carbon chain length  $C_{18}$ – $C_{24}$ . The range and relative abundance of these plant-derived components was variable between and even within sites. Therefore, there is no reason to suspect that the plant material that was processed in mortaria was necessarily of a single type. Further, there is no discernible qualitative difference between the plant-derived components observed in the mortaria and those observed in Iron Age and Roman 'cooking' vessels. The concentration of  $C_{18:0}$  in plant tissues is very low and as such, the stable carbon isotopic composition could not be measured in the residues that were almost entirely plant-derived. However, the stable carbon isotopic composition of individual fatty acids from the leaves, stems and seed oils of plants is undiagnostic of plant type,

other than to separate  $C_3$  and  $C_4$  species (Woodbury *et al.* 1998; Dungait *et al.* 2008, 2010) and therefore such values would not enhance our determination of the source of plant-derived lipids.

Biomarkers from plant resins were also detected in two mortarium sherds. The resins identified in sherds from Faverdale and Piercebridge are diterpenoid resins, from which the Pinaceae family (pine, cedar, fir) may be distinguished by the presence of components deriving from abietane and pimarane skeletons (Zavarin & Snajberk 1980; Evershed *et al.* 1985; Simoneit 1986; Serpico & White 2000). In these residues, the identification of abietic acid, pimaric acid and related degradation products, including dehydroabietic acid, indicates that Pinaceae resin was associated with the mortarium, and further, the presence of the methyl ester of dehydroabietic acid is indicative that the resin was heated (e.g. pitch). It is unlikely that the mortarium was used directly to prepare resin or pitch as the concentrations

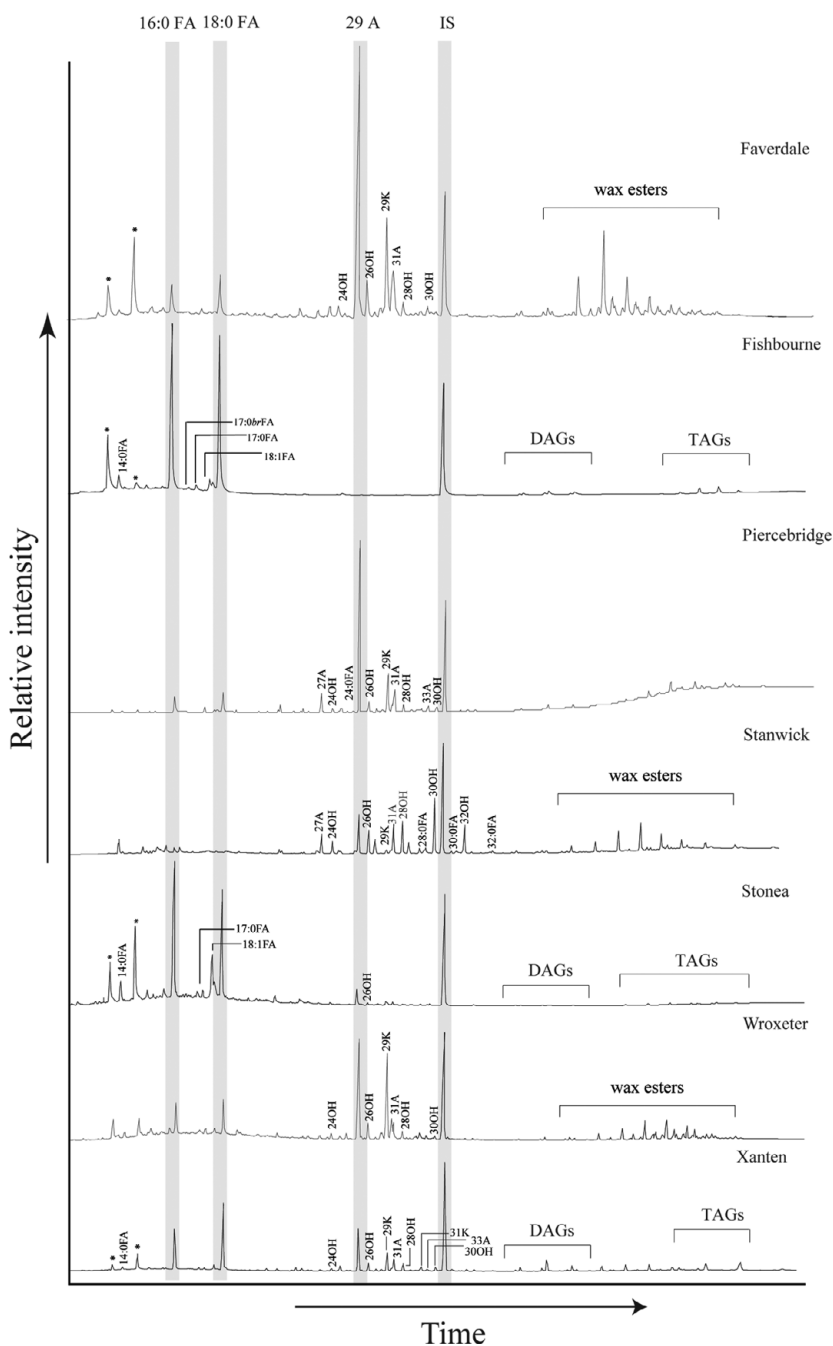


Figure 4. High temperature gas chromatograms of typical total lipid extracts (trimethylsilylated) obtained from sherds from the seven sites discussed in the text. Abbreviations: X:y FA = free fatty acid with X carbon atoms and y degree of unsaturation; X OH = n-alkanol with X carbon atoms; X A = n-alkane with X carbon atoms; X K = ketone with X carbon atoms; DAGs = diacylglycerols; TAGs = triacylglycerols; IS = internal standard (n-tetratriacontane); \* = phthalate contamination.



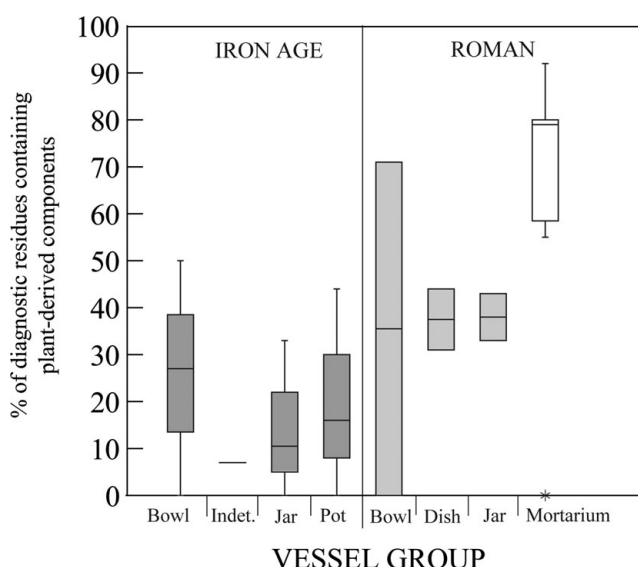


Figure 5. Box plot showing the proportion of residues containing plant-derived components identified in the Iron Age and Roman assemblages. The analysis of Iron Age vessels produced 141 diagnostic residues from four sites: Danebury (Hamps.) Yarnton Cresswell Field (Oxon.), Maiden Castle (Dorset) and Stanwick, (Northants; Copley et al. 2005). The Roman 'cooking' vessel group includes 72 diagnostic residues from Stanwick and Faverdale (Co. Durham), whilst the mortaria sample group includes 125 diagnostic residues from six British and one continental site: Faverdale, Fishbourne (W. Sussex), Piercebridge (Co. Durham), Stanwick, Stonea (Cambs.), Wroxeter (Shrops.) and Xanten (Westphalia, Germany).

of diterpenoids are very low; however, it is a possibility that these biomarkers result from their dissolution in a non-viscous commodity that had been stored previously in amphorae with a resin lining. Pine resins have previously been chemically identified on amphorae believed to contain wine (Peacock & Williams 1986; Heron & Pollard 1988; Colombini *et al.* 2005) and recently as a pitch coating in a Dressel 20 amphora from London (Stern *et al.* 2008), a form widely believed to have been used to transport olive oil (Tyers 1996). Resin acids from such a lining would readily dissolve in olive oil and moreover would easily detach and become mixed with the contents; as such, biomarkers for the pitch lining may have been transferred into subsequent preparation vessels.

Whilst plant components are widely detected in mortarium residues, degraded animal fats, characterised by a high relative abundance of  $C_{18:0}$  fatty acid (stearic acid) and distinctive distributions of intact triacylglycerols, are also frequently observed in residues from these vessels. The occurrence of animal-derived fats suggests that both animal and plant products were regularly prepared in the same mortaria, although it cannot be discerned whether these were mixed on the same occasions, or whether the mortarium was used separately for a variety of commodities. Pottery from Piercebridge contained unusually high concentrations of steroidal components, dominated by  $C_{27}$  sterols, stanols ( $5\alpha$  and  $5\beta$  epimers) and stanones, which are diagnostic of an animal origin. Plant-derived  $C_{28}$ – $C_{29}$  sterols and stanols, including campestanol,  $\beta$ -sitosterol and stigmastanol, were also identified in lower concentrations in the same residues. These findings agree with the other biomarker evidence,

supporting conclusions concerning the importance of both animal and plant product processing in mortaria.

The stable carbon isotopic values of individual fatty acids reflect the source of fats, allowing for example, the separation of fats of a predominantly non-ruminant (e.g. porcine), ruminant carcass (sheep/goat/cow) and ruminant dairy source (Dudd & Evershed 1998; Dudd *et al.* 1999; Evershed *et al.* 2002).  $C_{16:0}$  (palmitic acid) and  $C_{18:0}$  (stearic acid) are major saturated fatty acids in fats of animal origin and the stable carbon isotopic compositions of these components in mortarium residues were determined in order to further clarify the origin of the fats. These findings demonstrate that there is little evidence that non-ruminant (e.g. pig) fat ever comprised a significant component of mortarium contents. The majority of fats originate predominantly from ruminant (e.g. sheep, goat or cattle) adipose fats, therefore indicating cattle, sheep or goat meat or fat processing in the pots (Figure 6).

Although dairy fats were rare, three of ten mortarium residues subjected to GC/C/IRMS from Stanwick derived from a predominantly dairy source. Interestingly, the residues from both the Iron Age (Copley *et al.* 2005) and Roman cooking vessel assemblage at Stanwick exhibited a high proportion of milk or butter fats (>40%), suggesting an economy here with considerable dependence upon dairy products. Despite the unusually high frequency of dairy fat residues at Stanwick, the mortarium residues may still be easily distinguished from the cooking pot vessels due to the high frequency of plant-derived lipid components products and lower concentrations of lipid overall (Figures 2 & 3). Therefore, it seems likely that dairy products were widely used here to supplement, or replace, adipose products, perhaps due to their ready availability *or* the manifestation of a difference in local traditions. However, the broader role of mortaria appears consistent with sites elsewhere in Britain.

## Discussion

The interpretation of 125 diagnostic absorbed organic residues from Roman mortaria demonstrates that these vessels were used frequently or intensively to contain or process commodities of plant and animal origin. The animal products appeared to derive predominantly from the carcass although at one site (Stanwick), dairy products were extensively processed. However, we reject the hypothesis that mortaria were routinely used as a specialised vessel for processing dairy products (e.g. cheese-making vessels) since fats deriving from a predominantly dairy origin were otherwise rarely identified. Even at Stanwick, ruminant adipose fats and plant epicuticular waxes were more commonly identified in the mortarium residues than dairy fats, thereby precluding the possibility of a unique use for this vessel form.

Whilst the use of mortaria for grinding cereals cannot be disproven, a use solely for the processing of grain is not supported by the frequency of animal fats in the residues. However, this must be qualified by the observation that the larger mortarium forms analysed generally yielded poor and less-diagnostic residues and therefore the possibility of a special cereal-related function for the larger specimens cannot be discounted at this stage.

As a relatively 'multi-purpose' mixing bowl, it would be expected that there would be a bias towards the representation of commodities with a higher absolute lipid content, e.g. animal fats and plant oils, in the resulting residues. It is interesting to note that there is little

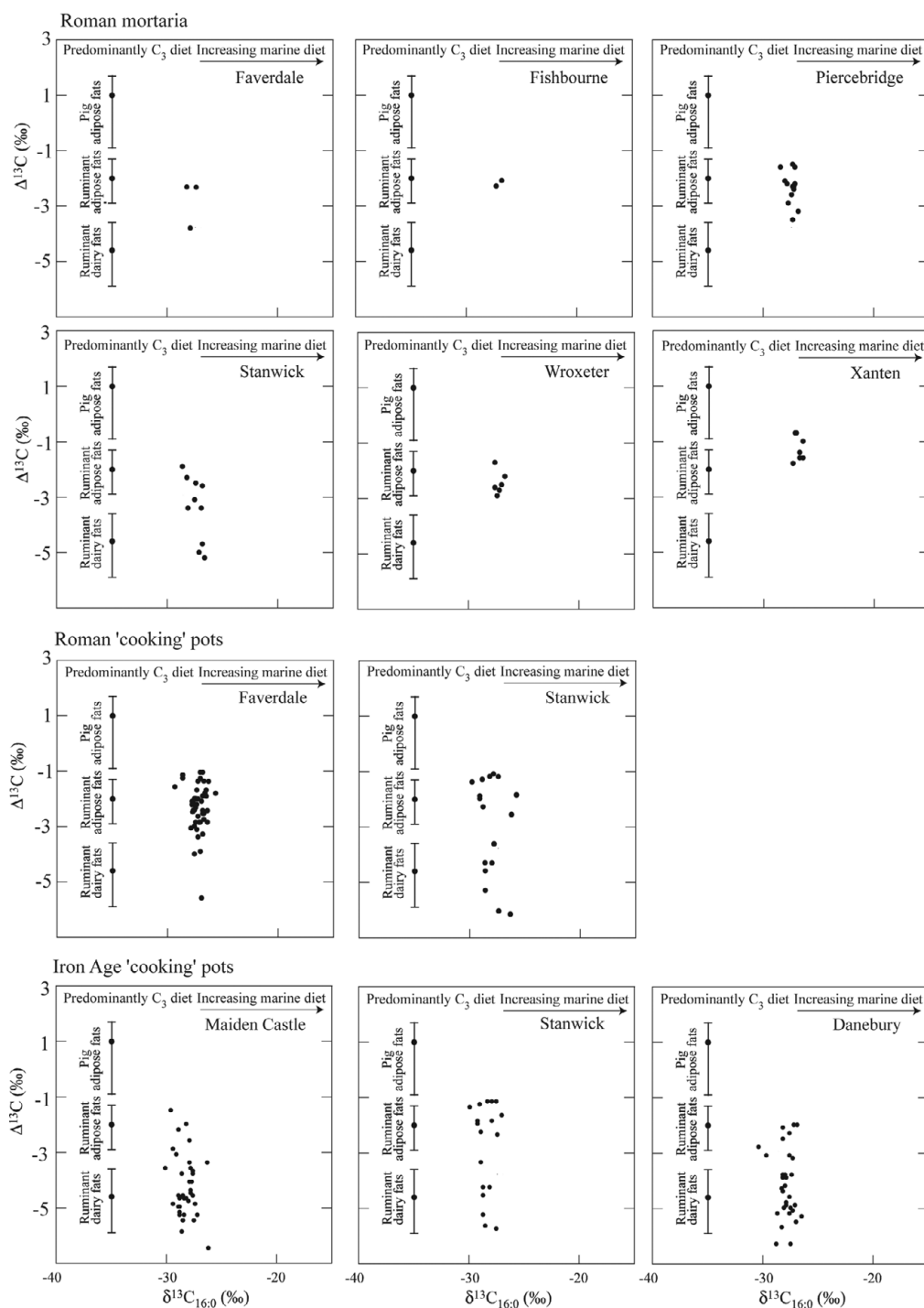


Figure 6. Scatter plots showing the  $\delta^{13}C$  values of palmitic acid ( $C_{16:0}$ ) plotted against the  $\Delta^{13}C$  ( $\delta^{13}C_{18:0} - \delta^{13}C_{16:0}$ ) from the archaeological pottery residues, with the ranges obtained from reference animal fats indicated on the left-hand axis. Iron Age  $\delta^{13}C$  values are previously published in Copley et al. 2005.

indication of plant oils. The isotopic signatures from oils are relatively enriched compared with ruminant fats and would therefore be expected to lie towards the non-ruminant region of the plot (Woodbury *et al.* 1998; Steele *et al.* 2010); however, mixing of oils with high concentrations of animal fat may mask a contribution of the former. It is possible that plant oil may be responsible for the slight, but statistically significant, enrichment of isotope values displayed in Xanten mortarium residues compared with British vessels ( $p = <0.002$  for  $\delta^{13}\text{C}_{16:0}$ ,  $\delta^{13}\text{C}_{18:0}$  and  $\Delta^{13}\text{C}$  values) although this may also be explained by a higher porcine contribution, as reflected in the faunal remains.

## Conclusion

The striking prevalence of degraded plant epicuticular wax components in the mortarium residues indicates that whatever the purpose(s) of mortaria, they fulfilled a unique role compared with the other domestic vessels investigated from British Iron Age and Roman sites. Whilst we cannot say whether this purpose was for culinary or for non-culinary (e.g. cosmetic or pharmaceutical) purposes, there is no equivalent ceramic vessel type amongst the Iron Age assemblages. This suggests a shift in cultural practice involving either new commodities, especially plants, or new apparatus or new recipes.

Whilst analyses of faunal and botanical assemblages from Iron Age and Roman sites in Britain indicate dietary transitions occurring over this period, it is argued here that the mortarium is not necessarily in itself a direct reflection of changing availability or selection of commodities. It is difficult to identify specific plant-types from the residues, but nonetheless plant epicuticular wax components are detected in Iron Age as well as Roman residues (Copley *et al.* 2005) and the difference lies in the frequency and abundance of these components in Roman mortaria, rather than the presence of unique components. The frequency of components of plant origin in Roman 'cooking' vessels compares well with observations from Iron Age domestic vessels and does not relate to a significant dietary shift. Similarly at Stanwick there is an unusually high prevalence of dairy fats observed in both the mortarium and 'cooking pot' residues, comparable with the frequency observed in the Iron Age vessels analysed from the same site (Copley *et al.* 2005), implying a long-term emphasis on dairy products that is reflected in all of the domestic utensils. It is argued that mortaria therefore do not necessarily, or solely, reflect the introduction of novel dietary components.

A second possibility is that mortaria were fulfilling a function which already existed, but had previously been fulfilled by other utensils. However, there is no ceramic or metal vessel from the pre-Roman period in Britain that is comparable in terms of form, use-wear and abrasive finish. Whilst stone saddle and rotary querns were produced during the Iron Age to grind cereals, the frequency of animal fat residues in Roman mortaria suggests that it is unlikely that mortaria were used to replace these. Moreover stone querns continued to be utilised in the Roman period (e.g. Peacock 1987; Shaffrey 2006).

The most likely context for the introduction of the mortarium is that it reflects a novel type of resource preparation involving plant and animal products. Traditionally, this has been interpreted as grinding and mixing meat with spices, oils and plant leaves to produce culinary dishes as described in the recipes of Apicius. A heavy emphasis on the processing of plant-derived products is ubiquitous at nearly all the sites investigated here, yet we cannot be

certain that this was to prepare ingredients for consumption; indeed a prevalence of plant-derived components is also a feature of Roman glass unguentarium contents (Ribechini *et al.* 2008). Neither do the residues support an entirely consistent usage of the mortarium in Britain. The unusual prevalence of dairy fats in the Stanwick mortarium residues is indicative of adaptation to pre-existing localised cultural or economic patterns. We would therefore argue that mortaria may be interpreted not as a direct reflection of a transition to 'Romanised' food-ways, but rather as a more complex and selective process of cultural adoption and adaptation in or beyond the kitchen.

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## References

- ALCOCK, J.P. 2001. *Food in Roman Britain*. Stroud: Tempus.
- BLÁZQUEZ, J.M. 1981. *Mosaicos romanos de Córdoba, Jaén y Málaga*. Madrid: CSIC, Instituto Español de Arqueología Rodrigo Caro.
- CHARTERS, S. 1997. Chemical investigations of absorbed lipids and laboratory simulation experiments to interpret archaeological pottery vessel contents and use. Unpublished PhD dissertation, University of Bristol.
- CHARTERS, S., R.P. EVERSHERD, L.J. GOAD, A. LEYDON, P.W. BLINKHORN & V. DENHAM. 1993. Quantification and distribution of lipid in archaeological ceramics: implications for sampling potsherds for organic residue analysis and the classification of vessel use. *Archaeometry* 35(2): 211–23.
- COLOMBINI, M.P., G. GIACHI, F. MODUGNO & E. RIBECHINI. 2005. Characterisation of organic residues in pottery vessels of the Roman age from Antioch (Egypt). *Microchemical Journal* 79: 83–90.
- COOL, H.E.M. 2004. Some notes on spoons and mortaria, in B. Croxford, H. Eckardt, J. Meade & H. Weekes (ed.) *TRAC 2003. Proceedings of the Thirteenth Annual Theoretical Roman Archaeology Conference, Leicester 2003*: 28–36. Oxford: Oxbow.
- 2006. *Eating and drinking in Roman Britain*. Cambridge: Cambridge University Press.
- COPLEY, M.S., R. BERSTAN, S.N. DUDD, V. STRAKER, S. PAYNE & R.P. EVERSHERD. 2005. Dairying in antiquity. I. Evidence from absorbed lipid residues dating to the British Iron Age. *Journal of Archaeological Science* 32(4): 485–503.
- DALBY, A. 1998. *Cato. On Farming. De Agricultura: a modern translation with commentary*. Blackawton, Devon: Prospect Books.
- DICKINSON, B. & K.F. HARTLEY. 1971. The evidence of potters' stamps on Samian ware and on mortaria for the trading connections of Roman York, in R.M. Butler (ed.) *Soldier and civilian in Roman Yorkshire: essays to commemorate the nineteenth centenary of the foundation of York*: 127–42. Leicester: Leicester University Press.
- DUDD, S.N. 1999. Molecular and isotopic characterisation of animal fats in archaeological pottery. Unpublished PhD dissertation, University of Bristol.
- DUDD, S.N. & R.P. EVERSHERD. 1998. Direct demonstration of milk as an element of archaeological economies. *Science* 282: 1478–81.
- DUDD, S.N., R.P. EVERSHERD & A.M. GIBSON. 1999. Evidence for varying patterns of exploitation of animal products in different prehistoric pottery traditions based on lipids preserved in surface and absorbed residues. *Journal of Archaeological Science* 26: 1473–82.

- DUNGAIT, J.A.J., G. DOCHERTY, V. STRAKER & R.P. EVERSLED. 2008. Interspecific variation in bulk tissue, fatty acid and monosaccharide  $\delta^{13}\text{C}$  values of leaves from a mesotrophic grassland plant community. *Phytochemistry* 69: 2041–2051.
- 2010. Seasonal variations in bulk tissue, fatty acid and monosaccharide  $\delta^{13}\text{C}$  values of leaves from mesotrophic grassland plant communities under different grazing managements *Phytochemistry* 71: 415–28.
- EVANS, J. 1995. Later Iron Age and ‘native’ pottery in the north-east, in B. Vyner (ed.) *Moorland monuments: studies in the archaeology of north-east Yorkshire in honour of Raymond Hayes and Don Spratt* (CBA research report 101): 46–68. York: Council for British Archaeology.
- EVERSHED, R.P. 2008. Experimental approaches to the interpretation of absorbed residues in archaeological ceramics. *World Archaeology* 40(1): 26–47.
- EVERSHED, R.P., K. JERMAN & G. EGLINTON. 1985. Pine wood origin for pitch from the Mary Rose. *Nature* 314(6011): 528–30.
- EVERSHED, R.P., C. HERON & L.J. GOAD. 1990. Analysis of organic residues of archaeological origin by High Temperature Gas Chromatography and Gas Chromatography-Mass Spectrometry. *Analyst* 115: 1339–42.
- EVERSHED, R.P., C. HERON, S. CHARTERS & L.J. GOAD. 1992. The survival of food residues: new methods of analysis, interpretation and application. *Proceedings of the British Academy* 77: 187–208.
- EVERSHED, R.P., S.N. DUDD, S. CHARTERS, H.R. MOTTRAM, A.W. STOTT, A. RAVEN, P.F. VAN BERGEN, H.A. BLAND. 1999. Lipids as carriers of anthropogenic signals from prehistory. *Philosophical Transactions of the Royal Society of London B* 354: 19–31.
- EVERSHED, R.P., S.N. DUDD, M.S. COPLEY & A.J. MUKHERJEE. 2002. Identification of animal fats *via* compound specific  $\delta^{13}\text{C}$  values of individual fatty acids: assessments of results for reference fats and lipid extracts of archaeological pottery vessels. *Documenta Praehistorica* 29: 73–96.
- FLOWER, B. & E. ROSENBAUM. 1958. *The Roman cookery book. A critical translation of The Art of Cooking by Apicius for use in the study and the kitchen*. London: Harrap.
- HARTLEY, K. 1973. The marketing and distribution of mortaria, in A.P. Detsicas (ed.) *Current research into Romano-British pottery* (CBA research report 10): 39–51. London: Council for British Archaeology.
- 1981. The mortaria, in C. Partridge (ed.) *Skeleton Green: a Late Iron Age and Romano-British site* (Britannia monograph series 2): 196–9. London: Society for the Promotion of the Roman Studies.
- 1985. The mortaria, in R. Niblett (ed.) *Sheepen: an early Roman industrial site at Camulodunum* (CBA research report 57): 92–93. London: Council for British Archaeology.
- 1990. The mortaria, in D. Neal, A. Wardle & J. Hunn (ed.) *Excavations of an Iron Age, Roman and medieval settlement at Gorhambury, St Albans* (English Heritage archaeological report 14): 191–5. London: Historic Buildings & Monuments Commission for England.
- 1999. The mortarium stamps, in A. Connor & R. Buckley (ed.) *Roman and medieval occupation in Causeway Lane, Leicester. Excavations 1980 and 1991* (Leicester archaeological monographs 5): 109–110. Leicester: University of Leicester Archaeological Services.
- HERON, C. & A.M. POLLARD. 1988. The analysis of natural resinous materials from Roman amphoras, in E.A. Slater & J.O. Tate (ed.) *Science and archaeology, Glasgow 1987. Proceedings of a conference on the application of scientific techniques to archaeology* (British Archaeological Reports British series 196): 429–47. Oxford: British Archaeological Reports.
- HERON, C., R.P. EVERSLED & L.J. GOAD. 1991. Effects of migration of soil lipids on organic residues associated with buried potsherds. *Journal of Archaeological Science* 18: 641–59.
- MAY, J. 1996. *Dragonby: report on excavations at an Iron Age and Romano-British settlement in North Lincolnshire* (Oxbow monograph 61). Oxford: Oxbow.
- OSWALD, F. 1943. The mortaria of Margidunum and their development from AD 50 to 400. *The Antiquaries Journal* 22: 45–63.
- PARMINTER, Y. & K. HARTLEY. 1996. The mortaria, in J. May (ed.) *Dragonby: report on excavations at an Iron Age and Romano-British settlement in North Lincolnshire* (Oxbow monograph 61): 567–73. Oxford: Oxbow.
- PEACOCK, D.P.S. 1987. Iron Age and Roman quern production at Lodsworth, West Sussex. *The Antiquaries Journal* 67: 61–85.
- PEACOCK, D.P.S. & D.F. WILLIAMS. 1986. *Amphorae and the Roman economy: an introductory guide*. London: Longman.
- PHELPS, J.J. 1923. The culinary use of mortaria. *Transactions of the Lancashire and Cheshire Antiquarian Society* 39: 1–15.
- REGAT, M., S. COLINART, L. DEGRAND & O. DECAVALLAS. 2001. Chemical alteration and use of beeswax through time: accelerated ageing tests and analysis of archaeological samples from various environmental contexts. *Archaeometry* 43(4): 549–69.

- RIBECHINI, E., F. MODUGNO, M.P. COLOMBINI & R.P. EVERSHERD. 2008. Gas chromatographic and mass spectrometric investigations from Roman glass unguentaria. *Journal of Chromatography A* 1183: 158–69.
- RUSH, P. 1997. Symbols, pottery and trade, in K. Meadows, C. Lemke & J. Heron (ed.) *TRAC 96. Proceedings of the Sixth Annual Theoretical Roman Archaeology Conference*: 55–64. Oxford: Oxbow.
- SERPICO, M.R. & WHITE. 2000. Oil, fat and wax, in P.T. Nicholson & I. Shaw (ed.) *Ancient Egyptian materials and technology*: 390–429. Cambridge: Cambridge University Press.
- SHAFFREY, R. 2006. *Grinding and milling. A study of Romano-British rotary querns and millstones made from Old Red Sandstone*. Oxford: Archaeopress.
- SIMONEIT, B.R.T. 1986. Cyclic terpenoids of the geosphere, in R.B. Johns (ed.) *Biological markers in the sedimentary record*: 43–99. Amsterdam: Elsevier.
- STEELE, V.J., B. STERN & A.W. STOTT. 2010. Olive oil or lard? Distinguishing plant oils from animal fats in the archaeological record of the eastern Mediterranean using gas chromatography/combustion/isotope ratio mass spectrometry. *Rapid Communications in Mass Spectrometry* 24: 3478–84.
- STERN, B., C.D. LAMPERT MOORE, C. HERON & A.M. POLLARD. 2008. Bulk stable light isotopic ratios in recent and archaeological resins : towards detecting the transport of resins in antiquity. *Archaeometry* 50(2): 351–70.
- TYERS, P. 1996. *Roman pottery in Britain*. London: Routledge.
- WOODBURY, S.E., R.P. EVERSHERD & J.B. ROSSELL. 1998. Purity assessments of major vegetable oils based on  $\delta^{13}\text{C}$  values of individual fatty acids. *Journal of the American Oil Chemists Society* 75(3): 371–9.
- YOUNG, C.J. 1973. The pottery industry of the Oxford region, in A.P. Detsicas (ed.) *Current research into Romano-British pottery* (CBA research report 10): 105–112. London: Council for British Archaeology.
- 1977. *The Roman pottery industry of the Oxfordshire region* (British Archaeological Reports British series 43). Oxford: British Archaeological Reports.
- ZAVARIN, E. & K. SNAJBERK. 1980. Oleoresins of Pinyons. *Journal of Agricultural and Food Chemistry* 28(4): 829–34.